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DEFECT DETECTION IN TEXTURE BY FOURIER ANALYSIS APPROACH

P K Kumaresan
Professor Computer Science and Engineering
VMVK Engineering College
(Vinayaka Missions University)
Salem 636308 Tamil Nadu

ABSTRACT:
Quality control is one of the basic issues in textile industry. Texture analysis plays an important role in automated visual inspection of texture images to detect their defects. The investment in an automated fabric defect detection system is more than economical when reduction in labor cost and associates benefits are considered. The inspection of real fabric defects is particularly challenging due to the large number of fabric defect classes, which are characterized by their vagueness and ambiguity. Many fabric defects are very small, which makes them very difficult to detect by only monitoring intensity change. Faultless fabric is a repetitive and regular global texture and Fourier transform can be applied to monitor the spatial frequency spectrum of the fabric. When the defect occurs in the fabric, its regular structure is changed so that the corresponding intensity at some specific positions of the frequency spectrum would change. In this paper, a simulated fabric model is used to understand the relationship between the fabric structure in the image space and in the frequency space. Based on the three dimensional frequency spectrums, two significant spectrum diagrams are defined and used for analyzing the fabric defect. These two diagrams are called the central spatial frequency spectrums. The defects are broadly classified into 3 classes. Double yarn, missing yarn and web or broken fabric. After evaluating these 3 classes of defects using some simulated models and real samples, seven characteristics parameters for central spatial frequency are computed.

1. INTRODUCTION

In textile industry, inspection is needed for maintaining fabric quality before sending any shipments to customers. Srinivasan et.al.[1] have stated that manufactures recover only 45-60% of their profits from second or off quality goods. Inefficiencies in industrial processes are costly in terms of time, money and consumer satisfaction [2]. The global economic pressure has gradually led businesses to ask more of itself in order to become more competitive. Currently much of the fabric inspection is done manually and even with the most highly train inspector, only about 70 % of the defects are being detected [3]. It is Imperative therefore to detect, to identify and to prevent these defects from reoccurring. An optimal solution for this would be to automatically inspect the fabric as it is being produced. Therefore, in order to lower the cost of the inspection process and to increase the competitive advantage of the products, it is necessary to automate the inspection process. An automated defect detection and identification system enhances the product quality and results in improved productivity to meet both customer needs and to reduce the costs associated with off quality. In this study, the central spatial frequency spectrum approach is introduced and examined. This method would reduce the computational time for defect detection and provide more parameters for defect classification. Before introducing this method, the characteristics of fabric structure in frequency spectrum is examined and some defect examples is described. After that, the procedures of the method and experimental results are discussed.

The Fourier transform characterizes the textured image in terms of frequency components. The periodically occurring features can be observed from the magnitude of frequency components. These global texture patterns are easily distinguishable as concentration of high-energy bursts in the spectrum. Liu and Jernigan [4] reviewed a set of 28 textural features extracted in the Fourier spectrum for texture analysis.

Escofet et al. [5] used the angular correlation of the Fourier spectra to evaluate fabric web resistance to abrasion. Chan and Pang [6] used the Fourier analysis for fabric defect detection. Seven textural features extracted from the vertical and horizontal frequency components in the Fourier spectrum are used to discriminate four defect types including double yarn, missing yarn, webs and yarn densities. Later, in [7], an approach based Fourier transform has been used to detect the various types of fabric defects. The central spatial frequency spectrum is used, from which seven significant characteristic parameters are extracted for detecting the type of defect. Further, they carried out experiments to detect only two classes of defects namely double yarn and missing yarn which found to be consistent for a number of samples. In [8], the author used the Fourier transform to reconstruct textile images for the defect detection. The line patterns in the textile images, supposed to be defects, were taken out by removing high energy frequency components in the Fourier domain using a one-dimensional Hough transform. The difference between the restored image and the original image were considered as potential defects. A similar idea was explored in [9], but low pass filtering was used to remove the periodic information. The Fourier transform of textile fabric can also be obtained in optical domain by using lenses and spatial filters. The fabric defect detection system using the measurements of the first- and the zero-order intensities have been developed [10, 11, 12, and 13]. Ciamberlini et al. [14] have described the design of spatial filters: a fixed filter adaptable for different types of fabric and a universal spatial filter for the detection of defects in textured materials. Campbell and Murtagh [15] have detailed a Windowed Fourier transform based method to detect defect on denim fabric samples.

2. BACKGROUND KNOWLEDGE

A. Fourier transform in image processing

Fourier transform has the desirable properties of noise immunity, translation invariance and the optimal characterization of periodic features. It states that it is possible to form any function as a summation of a series of sine and cosine terms of increasing frequency [16]. In other words, any space or time varying data can be transformed into a different domain called the frequency space. When we transform an image by taking brightness values from pixels, those pixel values are never continuous to begin with. The relationship between repetitive, regular and uniform fabric pattern in the image space and its spectrum in the spatial frequency can be linked by operating two dimensional Fourier transform. Let a two dimensional image be f(x,y), which is a real function representing the gray level in x,y spatial coordinates and let the image width and image length be N. Let F(n,m) denotes the Fourier transform of f(x,y) with n and m spatial frequencies. The general equation of two dimensional discrete Fourier transform is shown [17] :

$$F(n,m) = \frac{1}{N^2} \sum_{y=0}^{N-1} \sum_{x=0}^{N-1} f(x,y) * e^{-j2\pi (xn+ym)/N} \quad (1)$$

The computational time for Fourier transform is generally long. For two-dimensional discrete Fourier transform, it is proportional to the second order of the image size. In order to reduce the computation time, Fast Fourier Transform (FFT) is used. Fast Fourier transform is a discrete Fourier transform with some reorganization that can save enormous amount of time. For one-dimensional FFT, the computation time is $N\log_2 N$. Because of the separable transform being used to perform the two-dimensional transform, the computation time is proportional to $2N^2\log_2 N$. One of the advantage for the spatial frequency spectrum approach is the translation property of Fourier transform [18, 19] is that the magnitude of frequency spectrum does not change when the fabric is moved up. The spectrum is only varied by the change of fabric structure.

$$f(x-a, y-b) \leftrightarrow F(fx, fy) * e^{-j2\pi (f_x a + f_y b)/N} \quad (2)$$

In this study, the defects are broadly classified into 3 classes: Double yarn (Figure 2 and 3); missing yarn; webs or broken fabric. The double yarn (fill) is a change of spatial periodicity on the vertical axis [3]. The spectrum on the x-axis (fill direction) denotes the corresponding change of spatial frequency. In a simulated model of double yarn, d(x,y), the defect can be regarded as a substraction from a faultless fabric to a series of rectagle function, d(x,y). Because of the distributivity property of the Fourier transform,

$$F\{D(x,y)\} = F\{f(x,y) - d(x,y)\} = F\{f(x,y) - F\{d(x,y \quad (3)$$

Which means that the defect in the frequency space can be formed by subtracting the faultless fabric frequency spectrum from the Fourier transform of an irregular structure function d(x,y).

*B. **Central Spatial Frequency Spectrum***

Due to the nature of the fabric structure, many defects would occur along the x and y axis, which means that those characteristics would appear on the wrap (f_y) and fill (f_x) direction in the frequency spectrum. In addition, a three-dimensional graph of the frequency spectrum is very difficult to analyze. The method of central spatial frequency spectrum is therefore proposed in this study. This method extracts two diagrams along the f_x and f_y direction (F (fx,0) and F(0,fy)) from the three dimensional graph.

Seven significant features can be extracted in these two diagrams for describing defect characteristics. The equations of these parameters are shown below:

$$P1 = F(0,0) \quad P2 = 100 * F(f_{x1}, 0)/F(0,0)$$

$$P3 = f_{x1}$$

$$P4 = 100 * \left(\sum_{fxi=0}^{fx1} F(f_{xi}, 0)/F(0,0) \right)$$

$$P5 = 100 * F(0, f_{y1})/F(0,0) \quad P6 = f_{y1}$$

$$P7 = 100 * \left(\sum_{fyi=0}^{fy1} F(0, fyi)/F(0,0) \right)$$

Where, f_{x1} and f_{y1} corresponds to the first harmonic frequency. The first feature P1 is the average light intensity of the image, which is used to characterize the yarn density. Higher yarn density decreases the light intensity and P1 is decreases and vice versa. P5, P6 and P7 are used to monitor the wrap (vertical) threads structure, whereas P2, P3 and P4 are for detecting the fill (horizontal) threads structure. When defects occur, the amplitude of harmonic frequencies plus other changes would appear in the central spatial frequency spectrum. Features P2, P4, P5, and P7 are used to describe and detect these characteristics. Feature P3 and P6 are used to monitor the wrap and fill threads density in the image. Those features are more concentrated on analyzing the region between the central peaks and first peak (first harmonic frequency) because higher harmonic frequency components are significantly distorted in a real environment.

A defect such as double wrap is shown in figure 6(a). A comparison of the defect spectrum is shown in Figure 6 (b and c), where the defect is denoted by the solid line and the faultless fabric is denoted by the crosses. Both Figure 6(b and c) show that the central peak value (P1) of the defect fabric is lower than that of the faultless fabric. This is because one or more vertical (Wrap) threads are added in the faultless fabric, which leads to be lower light intensity in the defect image. The double wrap defect is a change of spatial periodicity in the horizontal axis, and therefore the |F(0,fy)| diagram is changed mostly. In this diagram (Figure 6(c)), the first peak value of the defect at f_{y1} =35 are lower than the faultless fabric first peak values and ripples occur. So P5 should be lower and P7 should be higher. The first peak location (P6= f_{y1} =35) is a fundamental yarn frequency, which means that the peak location is proportional to the yarn density. In this example, P6 is almost unchanged. A summary is shown in the second row of Table 1. With a similar interpretation, the double fill defect is a change of spatial periodicity in the vertical axis. Hence, the parameters P2 and P4 are changed because the defect only affects the |F(fx,0)| diagram.

The difference between missing yarn and double yarn is their fabric threads count [1]. Average light intensity P1 can show this characteristic. For missing yarn, higher P1 is expected because there is less thread in this defect [20]. Broken fabric and yarn densities variation are a change of periodicity in both x and y axis, and both |F(fx,0)|and |F(0,fy)| diagrams are mostly changed. P3 and P6 values are not changed in the broken fabric. This is because this defect is a instant change of the fabric density and it only affects P1, P2, P4, P5, and P7 values. The P1 is high because the fabric is broken and leads to increase of light intensity. Details of the expected results are summarized in Table 1.

3. EXPERIMENTAL SETUP

The experimental setup is as follows. It consists of an image acquisition system used to capture the image of the fabric which has to be inspected; histogram equalization is used to provide uniformity in density and then finally the operations of Fast Fourier transform is performed followed by central spatial frequency spectrum analysis. The system flow for this is as in Figure 1.

***Image acquisition*:**

Here, plain white fabrics are used. Defects with double yarn, missing yarn, web and fabric density variation were inspected and compared with faultless fabric. In the image acquisition, the image is captured; it is digitized and stored into computer memory. This image data is then processed by the defect detection procedure as shown in Figure 1.

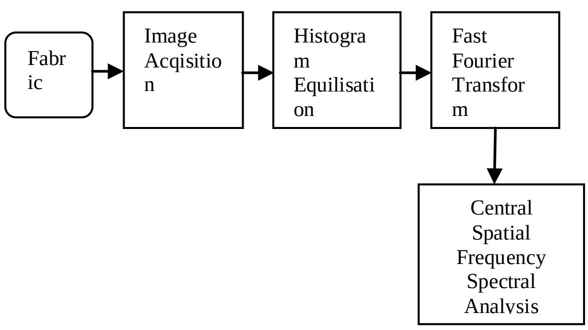

Figure 1. System flow for fabric defect detection.

Histogram Equalization:

Histogram equalization is performed to obtain a uniform density image histogram. This process extends the dynamic range of gray levels and increases the image contrast. The aim is to standardize the brightness and contrast of the images.

A. Fast Fourier Transform :

A Fast Fourier Transform (two point) transform is used for fast computation, which means that the image size is cut to 512 x 512 pixels in our experiment. This is because the image length and width should be a power of two. A Software package, MATLAB is used for this experiment. After the Fourier transform, the central spatial frequency diagram is extracted from three-dimensional diagram [21]. A real sample of double fill and its central spatial frequency spectrum diagrams are shown in figure 5 (b, c and d). By observing these two diagrams (Figure 5 (c and d) and comparing them with simulated diagram of double wrap Figure 4(b and c), the orientation of the defect mainly affects the particular diagram. For example, double wrap affects the parameters in the|F(0,fy)| diagram and double fill only affects the parameters in the|F(fx,0)| diagram. However, the high spatial frequency peaks in are loosely localized and embedded with some noise. The orientation of the defect mainly affects the relevant diagram.

4. RESULTS

Experimental results are used to verify the proposed approach. Here defect Fabric models and their corresponding real samples are used to examine this approach. Table 2 gives the difference in parameters obtained between simulated fabric and its defect. Table 3 gives the results of using real fabric samples. Missing wrap is an example for describing these parameters. Since this defect is missing one or more vertical thread, therefore, the significant parameters should be P1, P5, P6 and P7. As the fabric thread count is lower than the faultless fabric, the average light intensity of defect is higher. Due to this, P1 should be higher. Therefore, due to the irregular texture in the wrap direction, the first peak value is decreased and ripple occurs, which would cause P5 to be lower and P7 higher. Also, Table 2 and 3 can be used to classify the fabric defect type by noting the changes in the parameter.

5. CONCLUSIONS

In this study, as approach based Fourier transform has been used to detect the various types of fabric defects. The central spatial frequency spectrum is used here because, the three dimensional frequency spectrum approaches has been proposed here is very difficult to analyze. Seven significant characteristics parameters can be extracted from the central spatial frequency spectrum for detecting the type of defect. The variation in parameters in the defective fabric varies from that of the original non-defective sample as tabulated. Further analysis is being carried out to prove that the results are consistent for all types of cloth material and for particular defect. Here, we have analyzed and tabulated the results to detect only to classes of defects namely: double yarn and missing yarn and we have found our results listed above to be consistent for number of samples.

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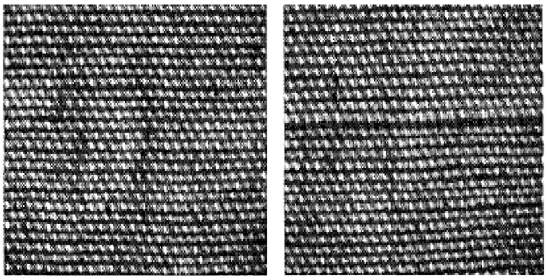
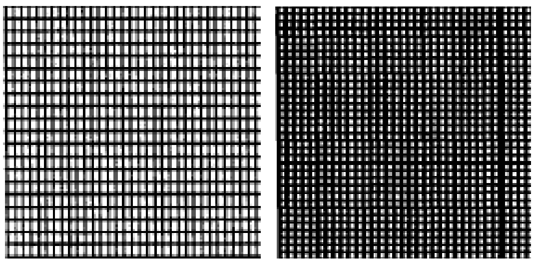


(a) (b)

Figure 2. (a) Real faultless fabric sample, (b) Real sample of double fill.



(a) (b)

Figure 3. (a) Simulated faultless fabric sample, (b) Simulated sample of double wrap

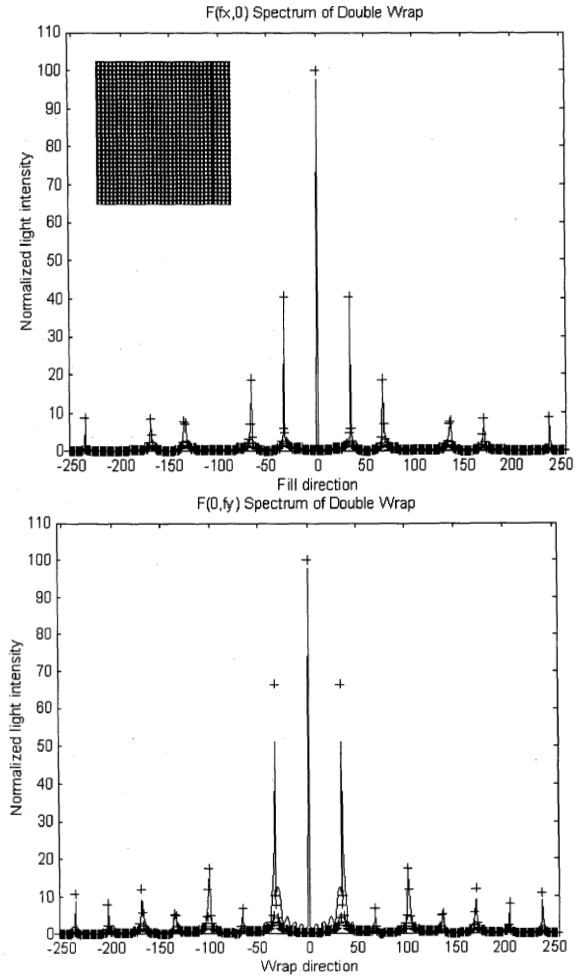
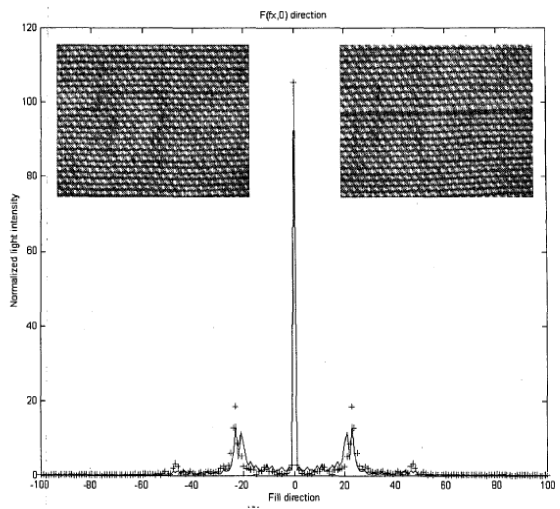


Figure 4. (a) Double yarn, (b) its fill direction spectrum, (c) its wrap direction spectrum.



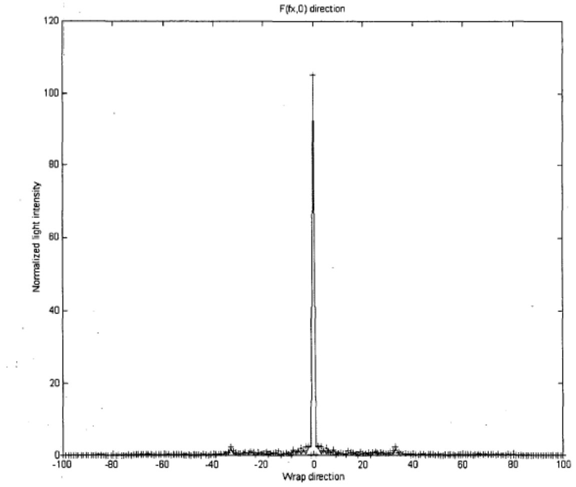


Figure 5. (a) faultless fabric, (b) double fill, (c) their fill direction spectrum, (d) their wrap direction spectrum.

TABLE 2
DIFFERENCE IN PARAMETERS OBTAINED BETWEEN A SIMULATED FABRIC MODEL AND ITS DEFECT

	P1	P2	P3	P4	P5	P6	P7
Double (Wrap) yarn	L	NC	NC	NC	L	NC	H
Missing (Wrap) yarn	H	NC	NC	NC	L	NC	H
Broken fabric (Web)	H	L	NC	H	L	NC	H

H: Higher , L:Lower , NC: No Change

TABLE 1
DIFFERENCE IN PARAMETERS PREDATED BETWEENT HE FABRIC AND ITS DEFECT

	P1	P2	P3	P4	P5	P6	P7
Double (Fill) yarn	L	L	NC	H	NC	NC	NC
Double (Wrap) yarn	L	NC	NC	NC	L	NC	H
Missing (Fill) yarn	H	L	NC	H	NC	NC	NC
Missing (Wrap) yarn	H	NC	NC	NC	L	NC	H
Broken fabric	H	L	NC	H	L	NC	H
Low fabric density	H	L	L	L	L	L	H
High fabric density	L	L	H	L	L	H	L

H: Higher , L:Lower , NC: No Change

TABLE 3
DIFFERENCE IN PARAMETERS OBTAINED BETWEEN A REAL FABRIC AND ITS DEFECT

	P1	P2	P3	P4	P5	P6	P7
Double (Fill) yarn	L	L	NC	H	NC	NC	NC
Missing (Wrap) yarn	H	NC	NC	NC	L	NC	H
Broken fabric (Web)	H	L	NC	H	L	NC	H

H: Higher , L:Lower , NC: No Change